Apparatus

1. Gas chromatograph equipped with recorder

2. Detector, Electron Capture

3. Gas chromatograph columns

   Two unlike columns of non-polar and semipolar type suitable for pesticide analysis (e.g. glass 1/4" x 6 ft packed with 10% DC200 silicone fluid on 80-100 mesh Anakron ABC.)

4. 500 ml Kuderma-Denish glassware (Kontes K-570000)

5. Chromatographic column 400 x 22 mm (Kontes K-420550, C-4) with adapter, hose connector type (Kontes K-185030)

6. Separating funnel 250 ml (Kontes K-633030)

7. Evaporative Concentrator (Kontes K-569250)

8. Concentrator tube (Kontes K-570050) graduated in 0.1 ml to 1 ml

9. Separatory funnels (125 ml, 1000 ml with Teflon stopcocks)

10. Volumetric flask 250 ml

11. Florisil-PR Grade (60-100 mesh) prepared after the method of Hall (44)

12. Silicic acid, Mallickrodt 100 mesh

13. Glass Wool - hexane extracted

14. Centrifuge tubes 40 ml Pyrex

15. Soxhlet Extractor, 250 ml

16. Magnetic stirrer with teflon control bar, hexane extracted

17. 1 gallon sample bottles, with teflon caps

18. 10 ml transfer pipette

19. Celite 545 washed

20. Air regulator

Reagents, Solvents, and Standards

1. Sodium chloride ACS saturated solution

2. Sodium sulfate ACS granular anhydrous, conditioned for 4 hrs at 400°C

3. Diethyl ether - nanograde

4. Hexane, acetonitrile, methanol, methylene chloride, petroleum ether (BR 30-60°C) - pesticide grade

5. Standards - appropriate organochlorine and arochlors for elements in question

Calibration

1. Gas chromatograph conditions were considered acceptable when response to heptechlor epoxide was 50% of full scale for < 1 ng (nanogram) injection (full scale - 1×10^{-9} amp). Detector response for quantitative work was kept in the demonstrated linear range.

2. Standards were injected frequently as a check on detector and column stability.

Sample Preparation

1. Adjusted pH to near 7.0.

2. If the solids content of the combined sewer overflow sample was high (as with sludges and some influent samples), liquid-liquid partition was not possible due to emulsion formation. Under these conditions the sample aliquot was centrifuged and the supernatant treated as detailed in the extraction section below. The solids were combined with anhydrous Na_2SO_4 and extracted as discussed below.

3. For a sensitivity of 1 µg/l, sample aliquots were between 50 to 100 ml.

Extraction

1. Two methods of extraction could be employed depending on the nature of the sample. Unless the sample appeared to be low in solids and organics, such as a well treated effluent sample, it was necessary to separate the solids from the liquid and extract each separately. The extracts could then be combined and concentrated as a single extract.

2. Liquid - liquid extraction was employed for samples of low solids and organic content. The procedure used for liquid-liquid extraction is described as follows:

Place an aliquot of the sample in a one liter separatory funnel and make the column up to 500 ml using distilled water. Add 30 ml of 15% methylene chloride in hexane (V:V) and shake vigorously for two minutes. Allow the phases to separate and drain the water layer into a clean Erlenmeyer flask. Pass the organic layer through a 3-4" column of anhydrous Na_2SO_4 and collect in a 500 ml K-D flask. Return the water phase to the separatory funnel and rinse the Erlenmeyer with a second 30 ml volume of solvent. Add the solvent to the separatory funnel and complete the extraction procedure. The water phase should be extracted with three 30 ml aliquots of solvent. Concentrate the extract on a water bath to 5 ml.

3. If an emulsion was formed between the water and solvent phases, it was necessary to remove the solids using the following procedure:
   Place suitable aliquots of the high solids content sample in clean (hexane washed) glass centrifuge tubes. Decant the supernatant into a one liter funnel and extract the pesticides as outlined in item 2 above. Remove as much of the centrifuge cake as is possible with a glass rod and combine it with hexane washed anhydrous sodium sulfate in a large mortar and pestle. Work the sample to free flowing dry state by continuously adding small amounts of anhydrous sodium sulfate. Add a small amount of sodium sulfate to the centrifuge tube to dry any remaining sample and aid in removing it. Combine all the dried sample and pour it into a glass Soxhlet extraction thimble. To prevent the dried sample from packing too tightly, layer glass beads at about 1 inch intervals in the extraction thimble. Place the filled thimble in a soxhlet apparatus by pouring them through the filled extraction thimble. Extract the sample for 6 to 8 hours. Take the extract just to dryness on a water bath in a K-D assembly, cool and wash the K-D assembly with hexane and adjust sample to 5 ml.

4. The concentrate was analyzed quantitatively to determine:
   a. If organochlorine pesticides were present
   b. If PCB's were present
   c. Combination of a and b
   d. If elemental sulfur was present
   e. If response was too complex to determine a, b, or c

5. If a, determined organochlorine pesticides.

6. If b, determined PCB's

7. If c, compared peaks obtained to standard arochlors and determined which Arochlors were present. If Arochlor peaks were analogs of #1254 and #1260, the PCB's were separated from DDT and its analogs by the combination of Florisil column and silicic acid column technique. If other Arochlor analogs were present, further confirmation with the micro-alkali technique was employed.

8. If d, remove sulfur.

9. If e, the applicable separation procedures described below were followed.

Cleanup and Separation Procedures

(i) Acetonitrile Partition for removal of fats and oils. (note: not all pesticides are quantitatively recovered by this procedure. Efficiency of partitioning for pesticides of interest should be demonstrated).

Transfer the 5 ml concentrated extract to a 125 ml separatory funnel and add enough hexane washings to bring volume to 15 ml. Extract the sample with four 30 ml portions of hexane saturated acetonitrile by shaking vigorously for one minute. Combine and transfer the acetonitrile phases to a one liter separatory funnel and add 650 ml of distilled water. Add 40 ml of saturated sodium chloride solution. Mix thoroughly and extract with two 100 ml portions of hexane. Combine the hexane extracts in a one liter separatory funnel and wash with two 100 ml portions of water. Discard the water layer, pass the hexane layer through a 3-4 inch sodium sulfate column into a K-D flask and rinse the funnel and column with three 10 ml portions of hexane. Concentrate the hexane extracts to 6-10 ml and analyze via GLC unless further cleanup is required.

(ii) Sulfur Interference - Elemental sulfur is encountered in most sediment samples, marine algae and some industrial wastes. The solubility of sulfur in various solvents is very similar to the organochlorine and organophosphate pesticides; therefore, the sulfur interference follows along with the pesticides through the normal extraction and cleanup techniques. The sulfur will be quite evident in gas chromatograms obtained from electron capture detectors, flame photometric detectors operated in the sulfur or phosphorus mode, and Coulson electrolytic conductivity detectors. If the gas chromatograph is operated at the normal conditions for pesticide analysis, the sulfur interference can completely mask the region from the solvent peak through aldrin.

This technique eliminates sulfur by the formation of copper sulfide on the surface of the copper. There are two critical steps that must be followed to remove all the sulfur: (i) all oxides must be removed to give copper a shiny, bright appearance that would make it highly reactive; (ii) the sample extract must be vigorously agitated with the reactive copper for at least one minute (46).

It will probably be necessary to treat both the 6% and 15% Florisil eluates with copper if sulfur crystallizes out upon concentration of the 6% eluate.

Certain pesticides will also be degraded by this technique, such

as the organophosphates, chlorobenzilate and heptachlor (see Table B-1). However, these pesticides are not likely to be found in routine sediment samples because they are readily degraded in the aquatic environment.

If the presence of sulfur is indicated by an exploratory injection from the final extract concentrate (presumably 5 ml) into the gas chromatograph, proceed with removal as follows:

a. Under a nitrogen stream at ambient temperature, concentrate the extract in the concentrator tube to exactly 1.0 ml.

b. If the sulfur concentration is such that crystallization occurs, carefully transfer, by syringe, 500 µl of the supernatant extract (or a lesser volume if sulfur deposit is too heavy) into a glass-stoppered, 12 ml graduated, conical centrifuge tube. Add 500 µl of iso-octone.

c. Add 2 µg of bright copper powder, stopper and mix vigorously one minute on a Vortex Genie mixer.

NOTE: The copper powder as received from the supplier must be treated for removal of surface oxides with 6N HNO_3. After about 30 seconds of exposure, decant off acid, rinse several times with distilled water and finally with acetone. Dry under a nitrogen stream.

d. Carefully transfer 500 µl of the supernatant-treated extract into a 10 ml graduated evaporation concentrator tube. An exploratory injection into the gas chromatograph at this point will provide information as to whether further quantitative dilution of the extract is required.

NOTE: If the volume transfers given above are followed, a final extract volume of 1.0 ml will be of equal sample concentration to a 4 ml concentrate of the Florisil cleanup fraction.

(iii) Florisil Column Cleanup - Place a charge of activated Florisil (the weight of the charge is determined by its Lauric Acid Value, see Hall (51)) in the Chromaflex column and settle by gentle tapping. Add a 1 cm layer of anhydrous sodium sulfate and pass 50-60 ml of petroleum ether through the column. When the petroleum ether is about 5 mm from the sodium sulfate, transfer the sample extract by decantation and petroleum ether washings to the column and elute with the following mixed ethers at 5 ml/minute. (NOTE: For both column chromatography procedures the elution rate is important. To quickly adjust this rate the lower part of a broken 25 ml burette equipped with teflon stopcock placed between the chromaflex column and the receiving vessel is most useful in making repetitive low adjustments without losing eluate.). Collect each eluate in a 500 ml K-D flask.

Table B-1. EFFECT OF EXPOSURE OF PESTICIDES TO MERCURY AND COPPER

Compound	Percentage Recovery Based on Mean of Duplicate Tests	
	Mercury	Copper
BHC	81.2	98.1
Lindane	75.7	94.8
Heptachlor	39.8	5.4
Aldrin	95.5	83.3
Heptachlor Epoxide	69.1	96.6
pp'-DDE	92.1	102.9
Dieldrin	79.1	94.9
Endrin	90.8	89.3
DDT	79.8	85.1
Chlorobenzilate	7.1	0
Arochlor 1254	97.1	104.3
Malathion, diazinon, Parathion, Ethion, Trithion-	0	0

Note: If the microalkali dehydrochlorination procedure is used, elemental sulfur is removed.

To the first elution (6% eluate) add 200 ml of 6% ethyl ether in petroleum ether (V/V); second elution, 200 ml 15% ethyl ether in petroleum ether. Most pesticides of interest will be in these eluates. Refer to Reference 52 for more details.

6% Eluate

Aldrin	Heptachlor	Strobane
BHC	Heptachlor epoxide	Toxaphene
Chlorodane	Lindane	Trefluralin
DDD	Methoxychlor	PCB's
DDE	Mirex	
DDT	Pentachlornitrobenzene	

15% Eluate

Endosulfan I	Dechloran
Endrin	Phtholate
Dieldrin	

Concentrate the eluates and analyze by GLC.

(iv) Silicic Acid Column Separation Procedure

A. Silicic Acid Preparation

a. Celite 545 must be oven dried and free of electron capturing substances (acid washed).

b. Silicic Acid - Oven dry for a minimum of seven hours at 130°C to remove water. Cool the silicic acid and weigh into a glass stopper bottle and add 3% water. Stopper bottle and shake well. Allow 15 hours for equilibrium to occur. Determine separation achieved by loading 40 µg of Arochlor #1254 and pp 'DDT in hexane on the column. Inadequate separation will mean readjustment of the water content of the silicic acid in recommended increments of 0.5%. More water is required when the PCB elutes in the polar solvent with pp 'DDE; less water when pp 'DDE elutes in the petroleum ether portion. Standardization is required for each new lot of silicic acid purchased. Once a batch of silicic acid is hydrated activity remains for about 5 days.

B. Column Preparation - Weigh 5 g of celite and 20 g of silicic acid and combine in a 250 ml beaker. Immediately slurry with 80 ml of petroleum ether. Transfer the slurry to the chromatographic column, keeping the stopcock open. Stir the slurry in the column to remove air bubbles, then apply air pressure to form the petroleum ether through the column. Do not allow the column to

crack or go dry and close the stopcock when air pressure is not being applied. Stop the flow when the petroleum ether level is 3 mm above the surface of the silicic acid. The adsorbent at this point should be firm and not loose shape if tapped.

C. Elution Patterns - Large amounts of PCB's or pesticides placed on the column will result in incomplete separation. The extracted sample placed on the column should contain no polar solvents and be ≤ 5 ml in volume. Place a 250 ml volumetric flask beneath the column and carefully add a suitable aliquot of the 6% florisil eluate, taking care not to disturb the surface of the silicic acid. Apply slight air pressure until the solvent level is each 3 mm from the surface of the silicic acid. Carefully position the 250 ml separatory funnel containing 250 ml of petroleum ether on the column and allow the petroleum ether to run down the sides of the column until the space above the silicic acid is one half full. Apply air pressure and adjust the flow rate to 5 ml/minute. When exactly 250 ml are collected, replace the volumetric flask with a 500 ml K-D flask and elute @ 5 ml/min with 200 ml of methylene chloride, hexane and acetonitrile (80:19:1, V/V) to recover the pesticides. Quantitatively transfer the petroleum ether eluate containg the PCB's to a 500 ml K-D and concentrate both eluates to 5 ml. Analyze via GLC. NOTE: the separation between the PCB's and pp 'DDE is very narrow; great care should be exercised in adjusting the elution flow rate and volume of the petroleum ether portion.

Petroleum Ether Eluate

Aldrin

Arochlors	#1221[a]	#1254
	#1252[a]	#1260
	#1258[a]	#1262

Hexachlorbenzene

Polar Eluate (Acetonitrile, Methylene Chloride, Hexane)

Arochlors	#1221[a]	Endrin
	#1242[a]	Heptachlor
	#1248[a]	Heptachlor epoxide
BHC		Lindane
pp'DDE		Toxaphene
pp'DDT		
pp'DDD		

a. These Arochlors divide between the two eluates. The earliest eluating peaks may occur in the polar eluate.

D. Confirmation Techniques - Qualitative confirmation by comparing relative retention time (RRT) of the constituents on two or more unlike columns is suggested as a minimum criteria for identification after appropriate cleanup and column chromatography.

If an Arochlor analog which does not completely occur in the petroleum ether eluate is suspected, the alkali-dechlorination procedure is strongly recommended (see Young et al (49)). In any event such confirmational techniques add greatly to the reliability of the residue analysis in the absence of more sophisticated mass spectroscopy instrumentation.

BENCH SCALE TEST METHODS

Gravity Sludge Thickening

The bench scale tests described herein can be used to determine whether sludge is amenable to thickening by gravity sedimentation with or without chemical aids. Data obtained using this procedure can be used for design of gravity thickening equipment. An example of thickener design using the Coe & Clevenger (8) and Mancini (9) methods is presented.

Procedure-

1. Obtain a sample of the sludge at the concentration typical of the expected sludge concentration.

2. Obtain a sample of this sludge for analyses (suspended solids and total solids).

3. Measure and record in centimeters the distance between the 100 ml and 1,000 ml marks on a 1 liter graduated cylinder.

4. Fill the cylinder with sludge to the 1,000 ml mark.

5. Start the stopwatch.

6. Record the position of the interface (in ml) with respect to time (in minutes). Continue recording at 2-10 min. intervals (or more frequently if necessary) for 2 hours or until no further settling or compaction occurs.

7. During the above (step 6) set aside the remaining sludge sample and allow it to settle for approximately 2 hours. After that time decant off the supernatant and save it for dilution water. Measure the total volume of supernatant and the total volume of settled

sludge and record. Obtain a sample of the settled sludge (250-300 ml) for analyses. (suspended solids, total solids, and specific gravity)

8. Conduct settling rate tests at several concentrations between the original (C_i) and the settled sludge (C_f) concentrations. These concentrations are obtained by appropriate dilutions of the settled sludge with the supernatant. These dilutions should cover the complete range between C_i and C_f. Recommended values are obtained by using the concentrations of $C = C_f - r(C_f - C_i)$; where 'r' is an arbitrary factor value of which can be selected to provide suitable concentrations between C_i and C_f. For example 'r' can have values such as 0.25, 0.5 and 0.75. The proper dilutions can then be made using the following equations.

   The initial sludge concentration, Ci, can be expressed as:

$$C_i = \frac{V_s C_s + V_f C_f}{V_i}$$

   where Ci = solids concentration of the original sludge
   C_s = solids concentration of the supernatant (assumed = 0)
   C_f = solids concentration of the settled sludge
   V_i = total volume of sludge before settling = $V_s + V_f$
   V_s = volume of the supernatant
   V_f = final sludge volume after settling

   or

$$C_i = \frac{V_f}{V_s + V_f} \; C_f$$

One liter of sludge of the desired concentration is obtained using the following equation:

$$M_f C_f + M_s C_s = 1000\ C$$

where M_f = ml of settled sludge
M_s = ml of supernatant
C = desired concentration

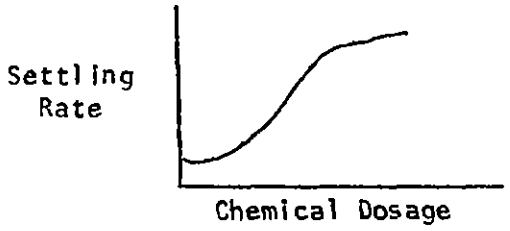
or

$$M_f C_f = 1000\ (C_f - r\ (C_f - C_i))$$

Substituting for C_i and simplifying $M_f = 1000 \left[(1-r) + r \left(\frac{V_f}{V_s + V_f} \right) \right]$

Add M_f ml of settled sludge to a 1 liter graduated cylinder. Fill to the 1000 ml mark using the supernatant. Mix thoroughly, start the stopwatch and record the position of the interface with respect to time. These tests can be run for a shorter period of time because only the initial settling rate is of importance and the later compaction rate is not needed. Repeat for all values of r. After settling, mix thoroughly and obtain a sample for suspended solids.

Gravity Thickening With Chemicals - Chemical addition may improve thickening or sedimentation properties of a sludge by forming a floc and increasing the settling rate. The initial step in testing with chemicals is to screen numerous chemicals for effectiveness. Among chemicals that can be screened are $FeCl_3$, lime, alum, and polyelectrolytes (cationic, nonionic and anionic). Screening tests are normally conducted in 100 ml graduated cylinders using various dosages of chemicals and combinations of chemicals. The test of effectiveness in these screening tests is the visual observation of floc formation. After selection of the chemical or chemicals, settling rate tests are conducted in 1 liter graduated cylinders at a wide range of chemical dosages. A graph of the settling rate versus chemical dosage generally yields a curve of the following form.



The optimum chemical dosage is at or near the break point of the curve, i.e. the point at which additional chemical increases the settling rate only slightly or not at all. A complete set of settling tests as described in the previous section is then conducted using chemicals at the optimum dosage. It should be noted that the chemical dosage used in these tests must be on a weight-weight basis, i.e. gm of chemical per kg of dry sludge solids. Correct amounts of chemical (in mg/l) to use at the various sludge dilutions can be determined using the following equation:

$$D = D_1 \left(\frac{M_f}{1000}\right)\left(\frac{V_f + V_s}{V_f}\right)$$

where D = chemical dosage at the test sludge concentration mg/l

D_1 = optimum chemical dosage with sludge at the initial concentration, mg/l

The dosages calculated in the above manner are those that are used on the sludge samples after mixing the settled sludge with the supernatant. Chemicals are added after the sludge is mixed to the desired concentration. The chemical is mixed with the sludge, flocculated if necessary and settled as described previously. The same mix time and flocculation time must be used for the entire series.

Data Analysis -

1. Plot the data obtained from the settling tests, i.e. position of the interface in ml versus time in minutes. Each graph will have the following configuration:

The settling rate is the linear portion of the curve. Determine the settling rate in ml/min and convert to meters/hr using the following:

$$S_1 = 6.67 \times 10^{-4} LS_2$$

where S_1 = settling rate, m/hr

L = distance between 100 and 1000 ml mark, cm

S_2 = settling rate, ml/min (slope of the settling curve linear section)

2. Plot the settling rate (m/hr) versus the sludge concentration (mg/l) on graph paper if necessary.

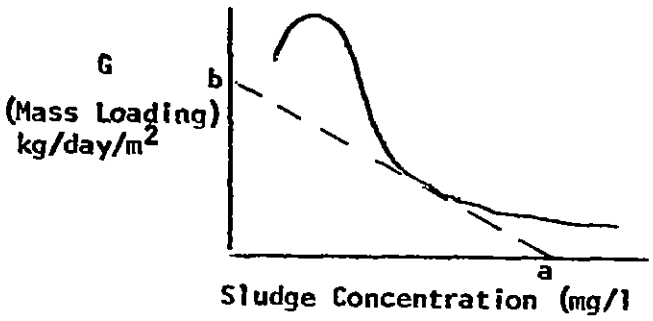
3. Construct a flux concentration curve from the settling rate curve i.e. mass loading in kg/day/sq m versus mg/l suspended solids

$$G = 0.024 (S_1) (C)$$

where G = mass loading, kg/day/sq m

S_1 = settling rate, at the tested concentration m/hr

C = sludge concentration, mg/l



Construction of a tangent to the curve from the desired underflow concentration (point a) will intersect the Y axis at the maximum mass loading (point b).

4. From the mass loading rate obtained above the minimum required surface area for thickening may be determined

$$A = 1.44 \times 10^{-3} \; C_i Q_i / G$$

where A = surface area required for thickening, sq m
C_i = feed sludge concentration, mg/l suspended solids
Q_i = feed sludge flow rate, l/min
G = design solids loading, kg/day/sq m

5. The surface area for clarification must also be checked to see which process is limiting - clarification or thickening. The underflow rate is determined first.

$$Q_u = \frac{C_i}{C_f} \; Q_i$$

where Qu = underflow flow rate, l/min
Q_i = feed sludge flow rate, l/min
C_i = feed sludge suspended solids concentration, mg/l
C_f = underflow sludge suspended solids concentration, mg/l

The effluent flow rate for design of clarification is then obtained by difference.

$$Qe = Qi - Qu$$

where Qe = effluent flow rate, l/min

The minimum surface area required for clarification is then:

$$A = \frac{0.06 \; Qe}{S_i}$$

where A = surface area required for clarification, sq m

Q_e = effluent flow rate, l/min

S_l = settling rate at the feed sludge concentration, m/hr

DISSOLVED-AIR FLOTATION SLUDGE THICKENING

It has been indicated that dissolved-air flotation may be used as a method of thickening sludge to a higher solids concentration in relatively shorter periods of time than other gravity thickening methods. Flotation may be applied to the concentration of sewage plant sludges as well as industrial waste sludges.

Bench scale studies are invaluable in determining the amenability of dissolved-air flotation to sludge thickening and in obtaining certain basic process and equipment design data. Set forth below is a test procedure for conducting sludge thickening tests using dissolved-air flotation (53).

Final effluent or primary effluent should be used as a source of pressurized flow. If another source is used as pressurized flow, the source should be indicated.

The rate of solids separation will be obtained by performing actual tests using the appropriate experimental apparatus. As a part of these tests, the following data should be obtained:

a. Floated sludge volume
b. Settled sludge volume
c. Flotation detention time
d. Volume of waste sludge used
e. Volume of pressurized flow used
f. Concentration of combined flow

The test conducted to obtain the above data should be performed in one liter graduates. Obtain the vertical distance between the 100 ml mark and the 1,000 ml mark in inches or other convenient units and record.

Experimental Procedure

1. Rate of solids separation test:

   The rate of solids separation of the major portion of the waste sludge solids is obtained by observing the solids-liquid interface during flotation and recording its upward travel with time. This test should be performed in a one-liter graduate.

2. Waste sludge volume:

   The amount of waste sludge to be placed into the one-liter graduate for thickening will vary with the initial waste sludge solids concentration

and with the ratio of pressurized flow volume/waste sludge volume to be used

Let the amount of waste sludge to be placed into the one-liter graduate for the test be calculated as follows:

$$X = \frac{V}{2Y + 1}$$

where X = volume of waste sludge to be placed in graduate, ml
Y = percentage waste sludge solids concentration
V = total volume of waste sludge and pressurized flow (usually 1000 ml)

For example, assume the waste sludge to be thickened has a solids concentration of 1%. From the equation above, the amount of waste sludge to be placed in the graduate is 333 ml, when V = 1000 ml.

The weight of the sludge in the graduate should be obtained and recorded. The weight of the sludge may be obtained by first determining the graduate tare (weight of empty graduate) on a laboratory beam balance. Record the graduate tare. Then, similarly obtain the weight of graduate containing the sludge to be thickened. Obtain the sludge weight by difference and record. The sludge in the graduate is now ready for the addition of pressurized flow.

3. Pressurized flow

The flotation pressure cell is filled approximately three-quarters full with relatively solids-free water. The cell cover is secured, and air is injected into the cell using compressed air or a tire pump until a pressure of 40 psig is attained. The cell is then shaken vigorously for about 30 seconds to facilitate solution of air in the pressurized flow source. Open the discharge valve located on the pressure cell and fill the attached rubber tubing with air-charged flow. Check the quality of the air bubbles formed. The rubber tubing is then inserted into the graduate (all the way down to the bottom of the graduate) containing the waste sludge to be thickened. The pet-cock on the pressure cell is again opened and the pressurized flow is allowed to enter the graduate at the bottom and mix with the waste sludge. Pressurized flow is added until the combined volume is 1000 ml. Move the tubing up and down in the cylinder to assure complete mixing. It is important that the pressure of 40 psig be maintained during the release of pressurized flow into the graduate.

Determine the total weight of the contents of the graduate and record it. Also determine weight of pressurized flow used by calculation and record it.

4. Rate of solids separation data

At the beginning of the test, the solids-liquid interface is at the bottom of the graduate or at zero volume. As flotation progresses, the solids-liquid interface moves progressively up the height of the graduate. The rate of rise of the major portion of the solids is recorded.

At times the solids-liquid interface may be vague and good judgment may have to be exercised in following this interface. Care should be taken to avoid following the interface formed by the air bubbles alone. In general, this interface lags behind the solids-liquid interface.

The form which may be used in obtaining the rate of separation is suggested by the following example. The flotation detention time should be 60 minutes.

Time (min)	Volume (ml)	POI (Position of Interface) (ft)
0	0	0
0.5	170	0.207
1.0	320	0.379
1.5	430	0.504
2.0	540	0.628
3.0	620	0.718
4.0	655	0.756
5.0	680	0.784
10.0	750	0.865
15.0	780	0.889
20.0	795	0.917
30.0	810	0.934
40.0	850	0.980
50.0	865	0.995
60.0	870	1.000

The ultimate data desired is the position of the interface at various time intervals throughout the test. The column above labeled "Volume" is used as a convenient means of obtaining the position of the interface at any given time. For example, in the hypothetical case shown above, the position of the interface at any given time may be conveniently obtained using the appropriate graduation mark on the liter cylinder as a reference. After the flotation test, the graduation marks may be converted to meters of height by actual measurement.

5. Analyses of data

The data derived from the bench testing is then used to estimate the scum concentration at various mass loading rates. This data is then graphically plotted. Optimum overflow rates are then selected from this plot for the design of dissolved-air flotation thickeners.

CENTRIFUGE TEST PROCEDURE

The purpose of this test is to determine the dewatering characteristics of sludge by centrifugation. Data obtained include the effects of centrifugal force, the effect of residence time, estimates of solids recovery, sludge concentration and sludge consistency. Procedures were developed by Vesilind (54).

Procedure

Approximately 2-4 liters of sludge are required to run a complete test series. If the sludge contains large or stringy materials it should be prescreened on a coarse screen to avoid erroneous results.

1. Mix the screened sludge well and obtain a sample.

2. Place 75 ml of sludge into each of the centrifuge tubes. NOTE: It is important that balanced amounts of samples be placed in opposite centrifuge tubes. Sample sizes other than 75 ml may be used but the amount must be the same in opposing centrifuge tubes.

3. Place in the centrifuge and spin for a predetermined time at the required centrifugal force. Suggestions for spin time are 30 seconds, 60 seconds, 90 seconds and 120 seconds. Suggested centrifugal forces are 400 g, 600 g, 800 g and 1000 g. The step by step procedure for this test using the Dynac (manufacturer of the centrifuge) Model CT-1360 centrifuge is as follows:

    a. Place the filled centrifuge tubes in the head.

    b. Turn the timer dial clockwise to the "hold" setting.

    c. Determine the rpm required to obtain the desired centrifugal force using Figure B-1.

    d. From Figure B-2 determine the setting on the speed control which will yield the required rpm with the number of centrifuge tubes used.

    e. Close and lock the centrifuge cover.

    f. Quickly turn the speed control knob clockwise to the required setting simultaneously starting the stopwatch.

    g. At the end of the predetermined spin time turn the speed control knob counter-clockwise to zero and immediately apply the brake until the head stops.

4. Record the sludge depth on a data sheet.

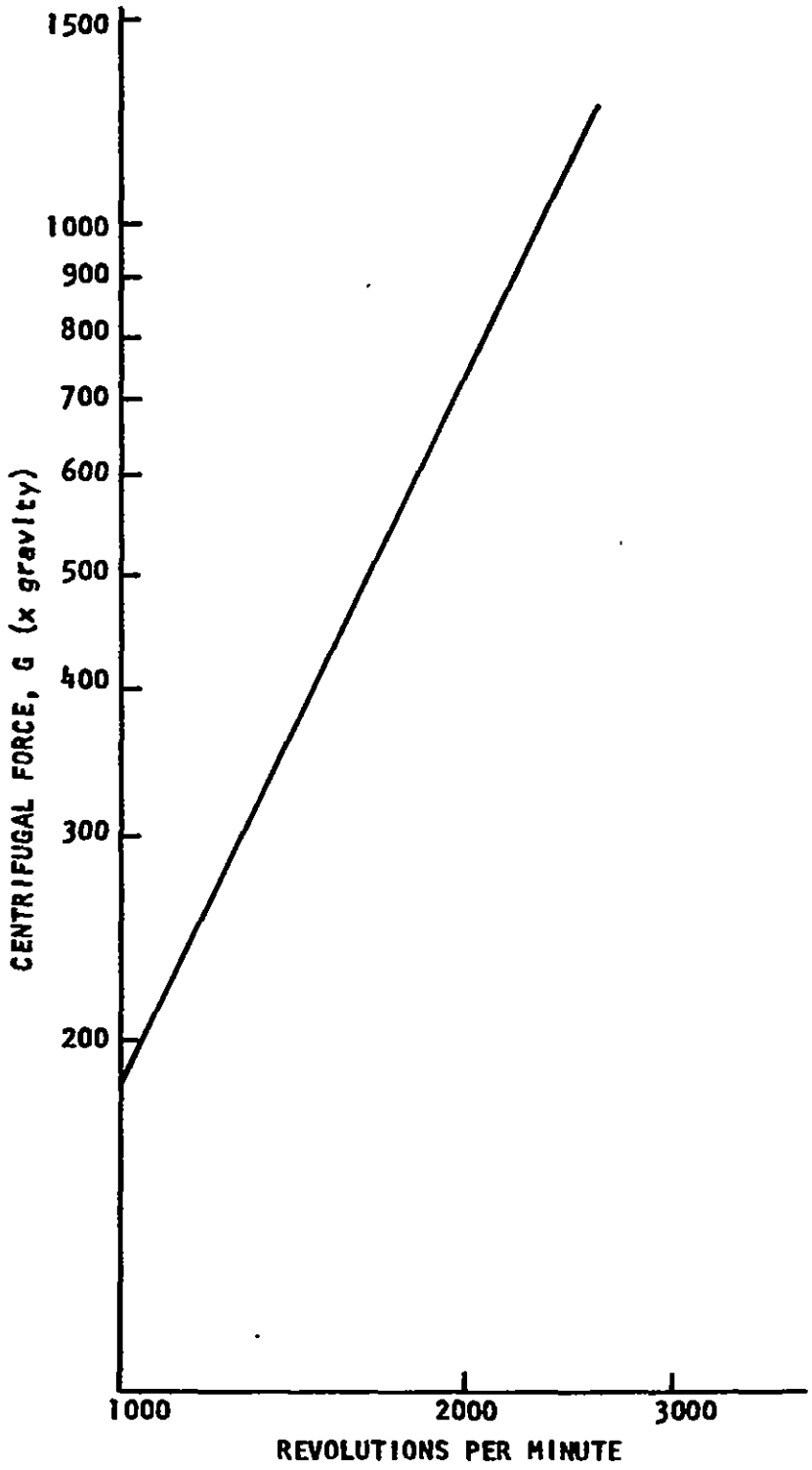


Figure B-1. Centrifugal force vs. RPM for Dynac Model CT-1360 centrifuge

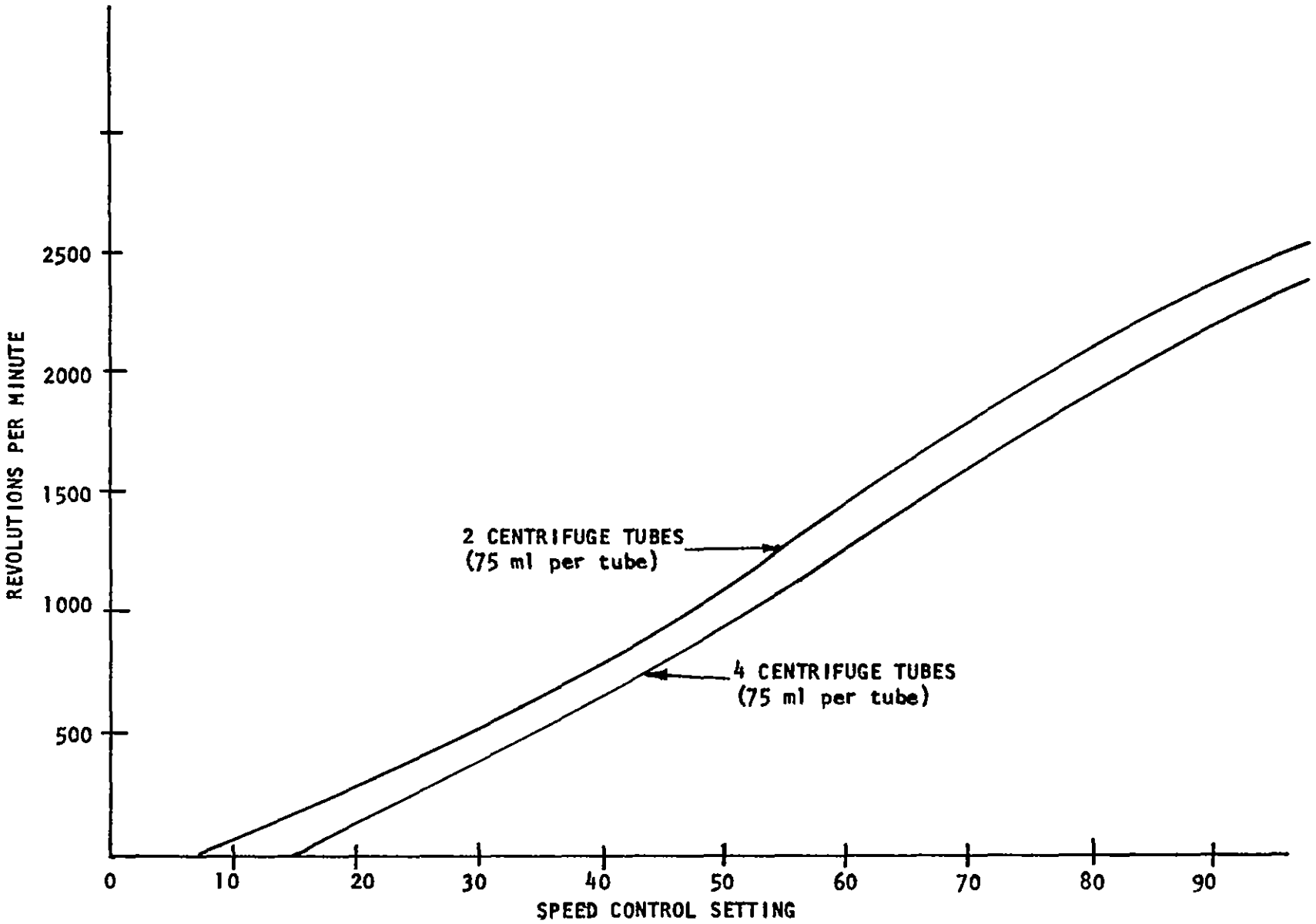


Figure B-2. RPM vs. speed control setting

5. Pour off the centrate from the tubes into a graduated cylinder. Record the centrate appearance and the total volume. Mix well and obtain a sample of the centrate.

6. Determine the consistency of the sludge using the glass rod (4 mm x 40 mm, 13 gm weight). Position the tip of the rod at the sludge surface. Drop the rod from this position, measure and record the depth which is penetrates.

7. Repeat steps 2 through 6 for all test conditions.

8. If chemical conditioning is desired, determine a suitable chemical dosage for floc formation. Dose each sludge sample with the same chemical dosage immediately prior to each centrifugation condition utilizing the same mixing time, degree of agitation and holding time for each test. Repeat steps 2 through 7 for these tests.

Data Analysis

1. Estimate the percent solids recovery for each test utilizing the following equation:

$$\% \text{ Recovery} = \frac{C_f - C_c \times 100}{C_f}$$

where C_f = suspended solids concentration in the feed sludge (mg/l)

C_c = suspended solids concentration in the centrate (mg/l)

2. Estimate the sludge solids concentration using the following equation:

$$C_s = \frac{V_f C_f - V_c C_c}{V_f - V_c}$$

where C_s = final sludge suspended solids concentration (mg/l)

C_f = feed sludge suspended solids concentration (mg/l)

C_c = suspended solids concentration in the centrate (mg/l)

V_f = total feed sludge volume centrifuged (ml)

V_c = total volume of centrate decanted (ml)

This parameter is only an indicator of the relative compactability of the feed sludge at various operating conditions.

3. Calculate the sludge penetrability to determine a correction factor for solids recovery using:

$$P = \frac{d_s - d_p}{d_s} \times 100$$

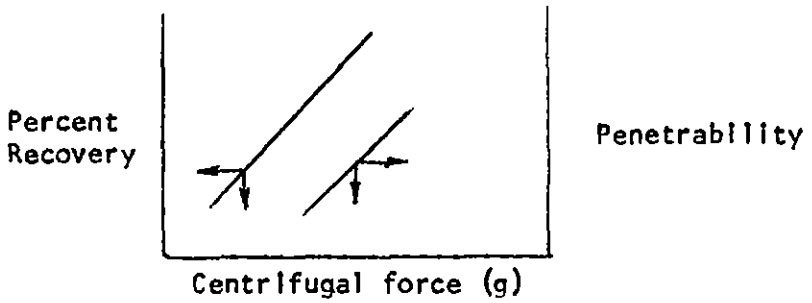
where P = sludge penetrability

d_s = depth of sludge after centrifuging

d_p = depth of penetration of the glass rod

The factor P is the percentage of the total sludge depth not penetrated by the glass rod.

4. Plot the recovery and penetrability versus the centrifugal force (x gravity) at constant spin times on log probability paper as below:



The data should plot as straight lines.

Estimate of Prototype Operation

At a constant centrifugal force read the recovery at one of the spin times. Also read the penetrability at the same spin time. An estimate of the recovery is then determined from the following equation,

$$\text{Recovery in Percent} = \left(\frac{C_f - C_s}{C_f}\right) \cdot \left(\frac{P}{100}\right)^{0.1} \times 100$$

VACUUM FILTRATION TESTS

Buchner Funnel Test Procedure

The Buchner funnel test is conducted to determine the optimum chemical dosage for filter leaf tests (55).

1. Moisten filter paper (Whatman #4) and place it in the Buchner Funnel. Apply a vacuum to obtain a seal. Empty water collected in filtrate receiver.

2. Analyze the sludge to be filtered for solids content.

3. Measure a volume of sludge that will provide a 3 mm to 6 mm thick cake.

4. Select the conditioning chemicals to be utilized and add a predetermined amount to the sludge to be conditioned. This should be reported as kg chemical/ton sludge dry solids.

5. Agitate the volumetric flask vigorously and allow the sludge to sit two minutes. Always agitate the sludge approximately the same amount for any one test series.

6. Add the sludge to the funnel and quickly apply vacuum. As soon as vacuum is applied, start the stopwatch. A vacuum reservoir may be needed to hold a constant vacuum.

7. Take filtrate volume readings with respect to time.

8. Continue the test until the cake cracks, or no filtrate is deposited for a one minute interval. Usually five minutes is sufficient. Be sure the cake edges do not shrink from the sides of the Buchner funnel. If it does, tap the edges of the cake to maintain a seal.

9. Sample cake for total solids.

10. Record filtrate temperature, vacuum level, and cake thickness.

11. Plot a curve of time/volume filtrate vs. volume filtrate and record the slope of the curve. The slope recorded should include only the linear portion of the curve.

$$a = 2PA^2b/\mu\omega$$

where a = specific resistance in sec^2/gm
P = vacuum level in gm/sq cm
A = area of Buchner funnel in sq cm
b = slope of t/v vs. v curve in sec/cm^6
μ = viscosity in Poise
$\omega = 1/[Ci/(100-Ci)) - (Cf/(100-Cf))]$

Ci - initial sludge moisture (%)
Cf = moisture concentration in cake (%)

12. Repeat steps 1 through 12 for several dosages of the same chemical.

13. Plot specific resistance vs. chemical dosage. The minimum point obtained on the curve is the optimum chemical dosage for the chemical tested.

Filter Media Selection Test Procedure

1. Select a cloth for testing in accordance with information available on chemical and physical conditions, sludge type and properties, and parameter qualities desired.

2. Moisten the cloth and place it in a Buchner funnel. Apply a vacuum to obtain a seal.

3. Analyze sludge sample for solids content.

4. Measure a volume of sludge equivalent to a cake thickness of 3 mm to 6 mm.

5. Condition the sludge with the optimum chemical dosage determined from the Buchner Funnel test as described in that test procedure.

6. Add the sludge to the Buchner Funnel. Apply a vacuum of about 50 cm Hg and start the stopwatch.

7. Measure the time to collect 100 cc of filtrate, 150 cc of filtrate, and 200 cc of filtrate. Discontinue test after 5 minutes.

8. Remove the cloth and measure cake thickness.

9. Note cake release as follows:

   excellent - cake peels off medium in pieces with slight amount of spatula aid.

   fair - cake must be taken off medium piece by piece with spatula.

   poor - cake will not come off medium even with maximum spatula use. Some solids left on medium.

10. Analyze the cake for solids content and the filtrate for suspended solids.

11. Wash the filter cloth on both sides with an intense water spray for 5 seconds.

12. Determine if any solids are deposited in the cloth interstices by eye or microscopic evaluation.

13. Repeat steps 1 to 12 three times utilizing the same sample medium.

14. Run a standard test on the sludge at optimum chemical dosage using #4 Whatman filter paper and a 50 cm Hg vacuum.

Vacuum Filter Leaf Test Procedure

1. Condition approximately 20 liters of sludge according to Buchner Funnel test results.

2. Place cloth selected from media screening test on the filter leaf and attach leaf hose to filtrate receiver.

3. Crimp the hose connecting the leaf to the vacuum source and set vacuum to desired level with the bleeder valve.

4. Immerse the leaf in the sludge so that the surface of the leaf is two to three inches below the sludge level. Release the hose and start the stopwatch simultaneously.

5. Keep the leaf submerged for a predetermined pickup time obtained from preliminary tests. For thin sludges, move the leaf slowly in a horizontal plane with a circular wrist movement at a rate of approximately 6 rpm. In thick sludges, the leaf should remain stationary. Keep thin sludges mixed with a small mixer. Thick sludges should be thoroughly mixed prior to the test.

6. At the end of the pickup time, the leaf is rotated out of the bucket.

7. The leaf is then held with the cake upward for the duration of the drying cycle. At the end of this time, vacuum is released. Adjust the vacuum as much as needed during the dry time to maintain vacuum level. Allow all filtrate to drain from the hose to the filtrate receiver.

8. Remove the cake from the filter leaf by blowing into leaf hose and dislodging it with a spatula. Analyze the cake for total solids. Note cake discharge and thickness.

9. Analyze filtrate for suspended solids, and record the filtrate volume.

10. Analyze solids content of remaining sludge. Two to four tests may be run on the same sample.

Preliminary Testing - In initial test, submerge test leafs for various periods of time and note at what time cake sloughing takes place, i.e. sludge will no longer build up uniformly, but falls off when leaf is removed from bucket. This is the maximum pickup time. The minimum pickup time is the time required to produce a cake thick enough to discharge.

Utilizing the maximum pickup time determined above, perform a leaf test and allow the cake to dry until it cracks or shrinks away from the edges of the leaf. This represents the maximum drying time. Run the remainder of the leaf tests according to steps 1-11 in the range of these established pickup and drying times.

Flocculation Test Procedure

1. Measure 50 ml to 100 ml into a 100 ml graduated cylinder and add a predetermined dosage of the chemical selected.

2. Invert the cylinder three times, keeping the palm on the top of the cylinder. (This is rapid mix.)

3. Add any additional chemicals in the order desired and repeat step 2.

4. Gently swirl the graduated cylinder with the wrist for a predetermined time interval. Observe the floc formation.

5. Repeat steps 1 to 4 for various chemical dosages, and compare the graduated cylinders visually to determine optimum chemical dosage. Floc size, supernatant clarity, and rate of floc formation all help in determining the optimum chemical dosage.

6. Utilize any other chemicals desirable.

APPENDIX C. COST DATA

Table C-1. ASSUMPTIONS FOR DEVELOPMENT OF COST DATA

1. Use a maximum sludge treatment time of 24 hours.

2. Assume 50 combined sewer overflows per year.

3. Capital costs for flotation thickening, centrifugation and vacuum filtration include $3,000 for a pump. Gravity flow assumed for gravity thickeners.

4. Power costs - assume motors running at 75% of full load current. Use 3¢/KWH.

5. Assume $6,000 for chemical feed system.

6. Chemical costs - polymer : $1.75/lb.
   lime : $9.00/100 lbs.
   ferric chloride: $6.5/100 lbs.

7. Assume 3% of initial capital investment for vacuum filters to be the annual maintenance required. Also assume 0.5 man hours per shift for operator attention.

8. Area estimates are for equipment only.

9. Assume $0.10 per gallon for hauling costs.

10. Labor costs based on $6 per man hour.

11. All costs are based on December, 1974 prices.

Table C-2. HUMBOLDT AVENUE - SUMMARY OF PERFORMANCE, COST AND SPACE REQUIREMENTS

Initial residual sludge volume: 34,700 gal.

Initial residual sludge concentration: 1.74% solids

Dewatering[a] process	Performance		Residual volume		Cost		Dewatered sludge hauling cost $/year	Total annual cost[b] $/year	Area sq ft
	Sludge % solids	Process effluent mg/l	Sludge gal.	Process effluent gal.	Capital $	Operating $/year			
Gravity thickening	6.0	870[c]	10,063	24,637	57,000	590	50,315	57,600	707
Flotation thickening	14.0	522[d]	4,313	30,387	111,000	4,960	21,565	39,563	450
Centrifugation	32.4	84	1,864	32,836	65,000	4,360	9,350	21,345	35
Vacuum filtration[e]	30.0	870	2,013	32,687	68,000	8,650	10,065	26,702	143

a. Bench tests done on the basis of sedimentation prior to dewatering. To convert storage basin into settling basin would be a capital expenditure of $516,000; $3,096 operating cost for a total annual amortized cost of $63,705.

b. Including amortization costs for a 20 year equipment life, 10% interest rate.

c. Based on 95% removal.

d. Based on 97% removal.

e. Estimated values based on vacuum filter performance under similar conditions found in this study (3#/ft/hr, 95% recovery).

Table C-3. DETAILS OF OPERATING COST ESTIMATES FOR HUMBOLDT AVENUE, MILWAUKEE, WI

Dewatering Method	Operating Costs ($/Year) Operating Labor	Maintenance	Chemical Costs	Power Costs	Total
Gravity Thickening	0	570	0	20	590
Flotation Thickening	1,800	2,220	0	940	4,960
Centrifugation	1,200	1,300	1,520	340	4,360
Vacuum Filtration	2,400	2,040	4,000	210	8,650

Table C-4. CAMBRIDGE, MA - SUMMARY OF PERFORMANCE, COST AND SPACE REQUIREMENTS

Initial residual sludge volume: 17,850 gal.[a]

Initial residual sludge concentration: 4.4% solids and 11% solids

Dewatering process	Performance: Sludge % solids	Performance: Process effluent mg/l	Residual volume: Sludge gal.	Residual volume: Process effluent gal.	Cost: Capital $	Cost: Operating $/year	Dewatered sludge hauling cost $/year	Total annual cost[b] $/year	Area sq ft
Gravity thickening[a]	14.0	2,200[d]	5,610	12,240	77,100	801	28,050	37,907	1,256
Flotation thickening	7.2	1,320[e]	10,908	6,942	109,000	4,935	54,540	72,278	370
Centrifugation	34.2	610	2,424	15,426	65,000	2,955	12,120	22,710	35
Vacuum filtration[f]	30.0	2,200	2,618	15,232	68,000	9,954	13,090	31,031	143

a. Based on mass balance of average conditions.

b. Including amortization costs for a 20 year equipment life, 10% interest rate.

c. Performed on a grab sample from Storm 1 at 11% solids.

d. Assume 95% capture.

e. Based on 97% caputre.

f. Estimated values based on vacuum filter perofrmance under similar conditions found in this study (3#/ft^2/hr; 95% recovery).

Table C-5. DETAILS OF OPERATING COST ESTIMATES FOR CAMBRIDGE, MA

Dewatering Method	Operating Costs ($/Year) Operating Labor	Maintenance	Chemical Costs	Power Costs	Total
Gravity Thickening	0	771	0	30	801
Flotation Thickening	1,800	2,060	325	750	4,935
Centrifugation	1,200	1,300	115	340	2,955
Vacuum Filtration	3,600	2,040	4,000	314	9,954

Table C-6. RACINE, WI - SUMMARY OF PERFORMANCE
COST AND SPACE REQUIREMENTS

Initial residual sludge volume: 121,000 gal.[a]

Initial residual sludge concentration: 8,430 mg/l

Dewatering process	Performance		Residual volume		Cost		Dewatered sludge hauling cost, $/year	Total annual cost[b], $/year	Area, sq ft
	Sludge % solids	Process effluent, mg/l	Sludge, gal.	Process effluent, gal.	Capital, $	Operating, $/year			
Gravity thickening	19	421[c]	10,200	110,800	29,300	313	51,000	54,755	177
Centrifugation[d]	20	--	5,100	115,900	158,000	12,790	25,500	56,849	200
Gravity thickening & centrifugation	32.9	1,321	3,100	117,900	105,300	4,544	15,500	32,413	205
Gravity thickening & vacuum filt.	23.2	1,821	4,397	116,603	97,300	10,663	21,985	44,077	320
Gravity thickening & flotation thickening	13.2	676	7,728	113,272	162,700	6,064	38,640	63,815	1,404

a. Based on a mass balance of average conditions.

b. Including amortization costs for a 20 year equipment life, 10% interest rate.

c. Assume 95% removal.

d. Basket centrifuge recommended since sludge not scrolable.

e. Assume 97% removal.

Table C-7. DETAILS OF OPERATING COST ESTIMATES FOR RACINE, WI

Dewatering Method	Operating Costs ($/Year) Operating Labor	Maintenance	Chemical Costs	Power Costs	Total
Gravity Thickening	0	293	0	20	313
Centrifugation	7,200	3,160	0	2,430	12,790
Gravity Thickening and Centrifugation	1,800	1,813	0	931	4,544
Gravity Thickening and Vaccum Filtration	3,600	2,333	4,396	334	10,663
Gravity Thickening and Flotation Thickening	1,800	2,961	372	931	6,064

Table C-8. HAWLEY ROAD, MILWAUKEE, WI - SUMMARY OF PERFORMANCE, COST AND SPACE REQUIREMENTS

Initial residual sludge volume: 36,675 gal.[a]

Initial residual sludge concentration: 3.65% solids

Dewatering process	Performance: Sludge % solids	Performance: Process effluent, mg/l	Residual volume: Sludge, gal.	Residual volume: Process effluent, gal.	Capital, $	Operating, $/year	Dewatered sludge hauling cost, $/year	Total annual cost[b] $/year	Area,[c] sq ft
Gravity thickening	10	1,825[d]	13,386	23,289	35,600	376	66,930	71,489	314
Flotation thickening	13	1,095[e]	10,297	26,378	102,300	5,682	51,485	69,183	796
Centrifugation	23.4	134	5,721	30,954	65,000	3,606	28,605	39,856	20
Gravity thickening & vacuum filtration	35.7	2,056	3,750	32,925	103,600	10,333	18,750	41,252	457
Gravity thickening & centrifugation	30.3	2,123	4,418	32,257	100,600	4,179	22,090	38,085	349

a. Scaled to entire outfall volume.

b. Including amortization costs for a 20 year equipment life, 10% interest rate.

c. Dewatering units sized based on treating entire outfall CSO of 36,675 GPD.

d. Assume 95% removal.

e. Use 97% removal.

Table C-9. DETAILS OF OPERATING COST ESTIMATES
FOR HAWLEY ROAD, MILWAUKEE, WI

Dewatering Method	Operating Costs ($/Year) Operating Labor	Maintenance	Chemical Costs	Power Costs	Total
Gravity Thickening	0	356	0	20	376
Flotation Thickening	1,800	2,046	1,026	810	5,682
Centrifugation	1,800	1,300	0	506	3,606
Gravity Thickening and Vacuum Filtration	3,600	2,596	4,003	334	10,333
Gravity Thickening and Centrifugation	1,800	1,656	197	526	4,179

Table C-10. SAN FRANCISCO, CA - SUMMARY OF PERFORMANCE, COST AND SPACE REQUIREMENTS

Initial residual sludge volume: 14,550 gal.[a]

Initial residual sludge concentration: 2.25% solids

Dewatering[a] process	Performance: Sludge, % solids	Performance: Process effluent, mg/l	Residual volume: Sludge, gal.	Residual volume: effluent, gal.	Cost: Capital, $	Cost: Operating, $/year	Dewatered sludge hauling cost, $/year	Total annual cost[b], $/year	Area, sq ft
Gravity thickening	4.5	1,125[c]	7,275	7,275	67,500	735	36,375	45,039	1,963
Flotation thickening	6.1	675[d]	5,367	9,183	85,000	3,728	26,835	40,547	170
Centrifugation	11.1	33	2,949	11,601	65,000	2,196	14,745	24,576	35
Vacuum filtration	18.2	123	1,699	12,751	62,000	7,600	8,995	23,878	128

a. Based on mass balance.

b. Including amortization costs for a 20 year equipment life, 10% interest rate.

c. Assume 95% removal.

d. Based on 97% removal.

Table C-11. DETAILS OF OPERATING COST ESTIMATES FOR SAN FRANCISCO, CA

Dewatering Methods	Operating Costs ($/Year) Operating Labor	Maintenance	Chemical Costs	Power Costs	Total
Gravity Thickening	0	675	0	60	735
Flotation Thickening	1,800	1,580	64	284	3,728
Centrifugation	600	1,300	127	169	2,196
Vacuum Filtration	1,800	1,860	3,731	209	7,600

Table C-12. KENOSHA, WI - SUMMARY OF PERFORMANCE, COST AND SPACE REQUIREMENTS

Initial residual sludge volume: 122,500 gal.[a]

Initial residual sludge concentration: 8,300 mg/l

Dewatering[a] process	Performance: Sludge % solids	Performance: Process effluent mg/l	Residual volume: Sludge gal.	Residual volume: Process effluent gal.	Cost: Capital $	Cost: Operating $/year	Dewatering sludge hauling cost $/year	Total annual cost[b], $/year	Area sq ft
Gravity thickening	1.0	--	101,675	20,825	87,700	2,010	508,375	520,686	1,590
Flotation thickening	3.1	249[c]	32,798	89,702	117,000	8,843	163,990	186,576	465
Centrifugation	8.9	54	11,424	111,076	170,000	13,030	57,120	90,118	200
Flotation thickening & centrifugation	6.6	356	15,405	107,095	182,000	17,116	77,025	115,401	500
Flotation thickening & vacuum filtration	15.2	331	6,689	115,811	185,000	24,631	33,445	79,806	608

a. Based on a mass balance.

b. Including amortization costs for a 20 year equipment life, 10% interest rate.

c. Based on 97% removal.

d. Based on basket centrifuge since zero corrected recovery indicates that the cake is not scrollable.

Table C-13. DETAILS OF OPERATING COST ESTIMATES FOR KENOSHA, WI

Dewatering Method	Operating Costs ($/Year) Operating Labor	Maintenance	Chemical Costs	Power Costs	Total
Gravity Thickening	0	877	1,073	60	2,010
Flotation Thickening	1,800	2,320	4,014	709	8,843
Centrifugation	7,200	3,400	0	2,430	13,030
Flotation Thickening and Centrifugation	2,700	3,560	9,809	1,047	17,116
Flotation Thickening and Vacuum Filtration	5,400	4,750	13,458	1,023	24,631

Table C-14. NEW PROVIDENCE, NJ - SUMMARY OF PERFORMANCE, COST AND SPACE REQUIREMENTS

Wet-Weather, Primary Clarifier Sludge

Initial residual sludge volume: 195,000 gal.[a]

Initial residual sludge concentration: 0.12% solids

Dewatering process	Performance		Residual volume		Cost		Dewatering sludge hauling cost, $/year	Total annual cost[b], $/year	Area, sq ft
	Sludge % solids	Process effluent	Sludge gal.	Process effluent, gal.	Capital $	Operating $/year			
Gravity thickening[d]	8.0	2,000[c]	3,000	192,000	41,300	1,273	15,000	21,124	177
Flotation thickening	5.9	1,200[d]	3,970	191,000	76,000	3,624	20,000	32,500	150
Gravity thickening & centrifugation	13.0[e]	170	1,750	193,250	100,300	3,737	8,750	24,268	200
Gravity thickening & vacuum filtration	27.5	2,082	85[f]	195,000	109,300	5,298	425	18,561	320

a. Based on mass balance.

b. Including amortization costs for a 20 year equipment life, 10% interest rate.

c. Assume 95% removal.

d. Based on 97% removal.

e. Assume prethickening to 4% solids prior to assumed centrifuge performance based on dry weather sludge data.

f. Done on 1% sample.

Table C-15. DETAILS OF OPERATING COST ESTIMATES
FOR NEW PROVIDENCE, NJ
Wet Weather Primary Clarifier Sludge

Dewatering Method	Operating Costs ($/Year) Operating Labor	Maintenance	Chemical Costs	Power Costs	Total
Gravity Thickening	0	413	840	20	1,273
Flotation Thickening	1,800	1,520	0	304	3,624
Gravity Thickening and Centrifugation	1,200	1,593	840	104	3,737
Gravity Thickening and Vacuum Filtration	1,200	2,453	1,573	72	5,298